BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART III. SOME EFFECTS OF POWER PLANT WASTE HEAT DISCHARGE ON THE ECOLOGY OF LAKE MICHIGAN

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Some Effects of Power Plant Waste Heat Discharge on the Ecology of Lake Michigan

by

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Preface

This project was undertaken with the cooperation of the Great Lakes Research Division of The University of Michigan, which provided me with every facility needed for this study. I express my sincerest thanks to Dr. John C. Ayers, Research Oceanographer for the Division, who coordinated this project and without whose help, encouragement, persistence, and support this project would not have been possible. I would also like to thank Dr. H. Lewis Batts, Jr. for his timely words of advice while the project was under way.

Miss Elsbieta Kopczynska faithfully completed the phytoplankton analysis in this report, Mrs. Jeanne Rose showed me the procedure for identifying and counting zooplankton samples, and the Division staff made my stay in Ann Arbor a valuable personal and educational experience.

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Introduction

The term "eutrophication", and the concept behind it originated with the publications of Weber (1907), Naumann (1917), and Thienemann (1918). Interest in this concept was mostly acedemic until publications by Berg et. al. (1958), Hasler (1947), and Sawyer (1947) appeared. Then interest became more active and the first application to the Great Lakes was made by Rawson (1951), who showed increased mineral content in Lakes Huron, Erie, and Ontario. After the above reports and others, reviews of the literature on the Great Lakes were made by Ayers (1962), Beeton (1965), Beeton and Chandler (1963), Chandler (1963), and Davis (1966). These authors, none of whom imply the Great Lakes are exempt from eutrophication, all indicate that eutrophication has been accelerated through the effects of man.

The man-caused wastes entering the Great Lakes are numerous and varied, ranging in composition from enormous quantities of domestic sewage and industrial waste to somewhat smaller amounts of detergents, fertilizers, pesticides, street salts, and toxics such as lead salts, cyanides, and chromates. These wastes enter the Great

Lakes via heavily polluted rivers, from direct sewer outfalls, from storm drainage systems and from local streams that carry anything from house and garden D.D.T. and lawn fertilizers to winter street salt into the tributaries of the Great Lakes Drainage.

One effluent that hasn't been given much consideration until recently has been the waste-heat discharged from electric power generating plants along the shores of the Great Lakes which use the lake water to cool the steam condensers of their fossil- or atomic-fueled plants and then return the heated (and sometimes chemically treated) water back to the lakes.

A survey of the literature indicates that most thermal pollution studies have been made on rivers and streams with the emphasis on problems encountered by fish. Since, in a lake situation, fish can swim away from local warm water areas such as those set up by power plant effluents, their value as thermal pollution indicators is questionable. However, the other biota found in a lake; zooplankton, phytoplankton, and benthos, are slower to migrate to new environments and may thus be better pollution indicators.

The magnitude of the waste-heat problem of the Great Lakes can be illustrated by the Federal Water Pollution Control Administration (1968). Their figures indicate that an average fossil-fueled plant drains 4,900 BTU/hr. into Lake Michigan and that a nuclear-fueled plant drains 7,800 BTU/hr. into the lake. Combining these statistics with a list of present and future power plants on Lake Michigan, it could be inferred that the resulting warm water areas could be the sites of tremendous ecological changes such as vastly increased chemical toxicity, decreased levels of oxygen and decreased levels of beneficial organisms resulting in decreased ability for self- purification.

Because only a few studies have considered the effects of warm water on lake biota, little information is available for a waste-heat study in a lake situation. It is hoped that this paper, whose purpose is to consider some of the ecological effects of heated power plant

effluents on the ecosystems of Lake Michigan, will answer some of the questions about thermal pollution, sound some warnings, and provide at least some data for future reference.

The literature offers an interesting but contradictory set of ideas about what happens when lake ecosystems are exposed to warm water. The full literature is too extensive to review here but a complete review is given by Wurtz and Renn (1965) and the following are given as examples of what the literature contains. Application of this literature to Lake Michigan will be discussed later.

Laberge (1959) indicated that elevated temperatures increase the toxicity of many poisonous materials and reduce the ability of the water to hold dissolved oxygen. In his laboratory experiments, 9.17 mg./l. of oxygen could be dissolved in water at 20°C, while at 30°C only 7.3 mg./l. could be dissolved. Metabolic rates of fish and other aquatic organisms increase as temperatures increase, indicating that more oxygen is required from water that is less capable of holding it.

Cairns' (1955) laboratory studies showed that diatoms grow best in water averaging 15-20°C while green

algae grow best in water averaging 25-35^{o}C. Blue-green algae have an optimum temperature of 30-40^{o}C. He states, "It is of interest that the blue-green algae are also those often found under conditions of organic or chemical pollution." Blue-green algae are not used in the lake's food chains as are diatoms and green algae, therefore they can become abundant (and eventually costly since they clog municipal water supplies and release foul odors and fishy tastes when they decay). Cairns also added that increase in temperature caused a reduction in the resistance of fish to toxic chemicals (which might be applicable to other biota as well) and that thermal loadings would be comparable to chemical pollutions since similar reactions were found in both cases. A small amount of heat produced little detrimental effect and was perhaps somewhat beneficial to the organisms. A moderate amount of heat caused the more sensitive organisms to drop out. Heavy amounts of heat, as in the plume of a power plant outfall, caused all but the very tolerant to die off, impairing the health of an average stream. Under conditions of very heavy loading, eventually all life disappeared causing the power of self-purification of the stream to be lost.

Markowski (1959) studied the effects of temperature increase on organisms in cooling ponds in Great Britain where water used for cooling was released into ponds before re-use or return to the rivers that it had come from. In the ponds, Markowski noted: "Observations on fresh water specimens indicate that they do not lose their vital capacity and they can live and reproduce in cooling ponds though the environmental conditions are strongly disturbed. The mass occurance of various species in cooling ponds confirm this supposition." Also in Markowski's study temperature measurements made by skin divers indicated that the less dense heated water from the outfall floated on top of the more dense and slightly cooler pond water, dispersing until an equilibrium was reached, the warmer apparently losing its heat to the atmosphere and surrounding water. He claimed too that the oxygen levels of the warmer water were not lowered, probably because of the turbulence from the outfall. Along this line, Wurtz (1967) mentioned that in the Schuylkill River, where water at 60°C could theoretically dissolve 4.5 mg./l. of O_2 and at 31.1°C could dissolve 7 mg./l., actually contained 12 mg./l. in the 37.3°C water at some places and as little as

5 mg./l. in 27°C water at others. Obviously, theoretical conditions do not always work in nature. He also said, "Numerous pathogens as represented by bacteria do not reproduce in water. As a matter of fact their persistence after discharge into water is chiefly a function of temperature; The higher the temperature the faster the die-away rate."

Beer and Pipes (1969) study of the littoral environment near the condenser outflow of the Commonwealth Edison Company's Waukegan, Illinois plant concluded, however, that, "No significant effect on the total near-shore environment along southwest Lake Michigan can be attributed to the discharge of cooling water from a large power station." Their statement was based upon temperatures, chemical, and biological analyses which indicate a floating effluent plume which dissipated most of its heat to the atmosphere. The benthic and planktonic communities, according to their report, indicate no definite effects from the heated discharge.

Methods and Materials

In order to investigate the effects of power plant effluents on Lake Michigan, offshore waters of four of the lake's 22 electric power generating facilities were investigated. At each facility survey stations were set up immediately in front of the water intakes and outflows of the plants and at varying intervals offshore to determine any immediate or tapering-off effects that would occur as the effluent waters flowed into the lake. The goal in setting up the stations was to obtain as representative a sample as possible of the surrounding area within the limits of the research vessel used since, in two cases, the shallow shore waters presented danger of running aground. Most of the samples were taken aboard The University of Michigan's research vessel "Mysis," and the remaining samples were taken from shores, piers, or bridges near the intake and outfall channels. Since zooplankton, phytoplankton, and benthos are among the best indicators of ecological change, temperature readings, Nansen bottle casts, #5 mesh net hauls, and Ponar dredge samples were taken at each station. The temperature readings, made at the surface, bottom, and intervals in between depending upon thermoclines present,

indicated length, depth, and direction of the warm water outfall plumes.

For phytoplankton samples, Nansen bottle samples were taken at the surface, bottom, and in cases where a thermocline existed, at the thermocline. In the outfall and intake channels one sample was taken at mid-depth since the water temperatures were homogeneous and the depths were no greater than 3m. 1000 ml. aliquots from each bottle were transferred to brown polyethylene bottles and preserved according to the procedures outlined by Utermöhl (1958). The samples were then taken to the laboratory for analysis.

Zooplankton samples were taken with a 0.5m. diameter #5 mesh plankton net equipped with a flow-meter to determine the volume of water that passed through the net. The net was lowered to within 1m. of the bottom and then drawn vertically to the surface where the flow-meter reading was taken and the net was washed down until the entire sample drained into the pint jar attached to the end of the net. The sample was then preserved with buffered formalin and taken to the laboratory for analysis.

Benthos samples were taken with a Ponar dredge (Powers and Robertson, 1967), hauled to the surface,

transferred to a wash tub then washed according to the techniques outlined by Powers and Robertson (1965). The samples were then preserved with buffered formalin and taken to the lab for analysis.

Laboratory Techniques.

The 1000 ml. preserved phytoplankton samples were transferred to a 1000 ml. graduated cylinder where the preservative-weighted phytoplankton cells settled for 24 hours. The supernatant water was drained off and a portion of the resulting sample was transferred to a plexiglass settling chamber and allowed to stand for another 24 hours. This subsample was then examined under a Leitz inverted microscope to determine the number and genus of the cells. Appropriate mathematical conversions were made to determine the number of cells per liter of water.

The zooplankton samples were transferred to a 1000 ml. graduated cylinder and diluted to 700 ml. A magnetic stirrer was used to distribute the mass evenly and a 5 ml. subsample, taken in 1 ml. aliquots, was transferred to a small sample dish where the sample was examined under a Leitz microscope to determine the number, genus, and species of each zooplankter. It was found that the 5 ml. subsample usually averaged 100 zooplankters,

ultimately a representative sample of the field area studied. Appropriate mathematical conversions were made to determine the number of cells per liter of water.

The benthos samples were transferred to a white-bottomed porcelain pan where the organisms were separated from the organic bottom material, removed with forceps, counted, and identified to family. Since the dimensions of the Ponar dredge were known, appropriate calculations were made to determine the number of organisms per square meter.

The power plants included in this study were the Campbell Plant, Consumers Power Company, Port Sheldon, Michigan; the B.C. Cobb Plant, Consumers Power Company, Muskegon Lake, Muskegon, Michigan; the Big Rock Point Nuclear Plant, Consumers Power Company, Charlevoix, Michigan; and the Port Washington Plant, Wisconsin Electric Power Company, Port Washington, Wisconsin. Exact locations of the survey stations are found on the charts in Appendix B.

Results

The data obtained for this paper are the results of five Great Lakes Research Division cruises on Lake Michigan in 1968. Because of difficult sampling conditions and flow-meter failure, the data are not complete. Despite the above, this project has enabled the author to become acquainted with the biota, to test methods and materials, to draw conclusions from the limited data obtained, and to compare these conclusions to those of others reported in the literature.

Temperatures:

As was mentioned earlier in this report, temperatures ideally were taken at the surface to bottom at each station. At Port Sheldon there were only two stations, immediately at the intake and outfall channels in strong current consequently no vertical temperatures were taken. At Muskegon the effluent channel empties into a marsh creek that separates to flow around an island (See Figure 9). Therefore, the warm water plume could not be followed accurately. At the Big Rock and Port Washington Plants, however, more complete studies of the plumes were made to trace the warm water after it was discharged into the lake.

At Charlevoix, the area around the power plant is very shallow, usually less than five feet deep, making it difficult to trace accurately the thermocline and bottom temperatures. Surface temperatures, therefore, were the only ones plotted (see Fig. 1). Most of the warmed water from the plant dissipated its heat within 500 yards of the outfall. The wind on this day was south 5-10 mph, directing the plume away from shore while residual current from earlier winds pushed it to the east.

At the Port Washington Plant the depths were great enough to warrant surface and bottom temperature samples (see Figs. 2 and 3). Figure 2 shows the surface temperatures of the harbor. The shallows area, a shallow anchorage for small boats, is loaded with organic matter and registers a temperature of 15°C as compared to the 12°C power plant outfall. Apparently more heat arises from the solar-heated shallows area than from the power plant. Figure 3 shows the bottom temperatures of the harbor indicating very limited thermal effect from the plant outfall. A comparison of the surface and bottom temperatures demonstrates that the warmer waters from the power plant and shallows area float above the bottom layers of water which are cooler.

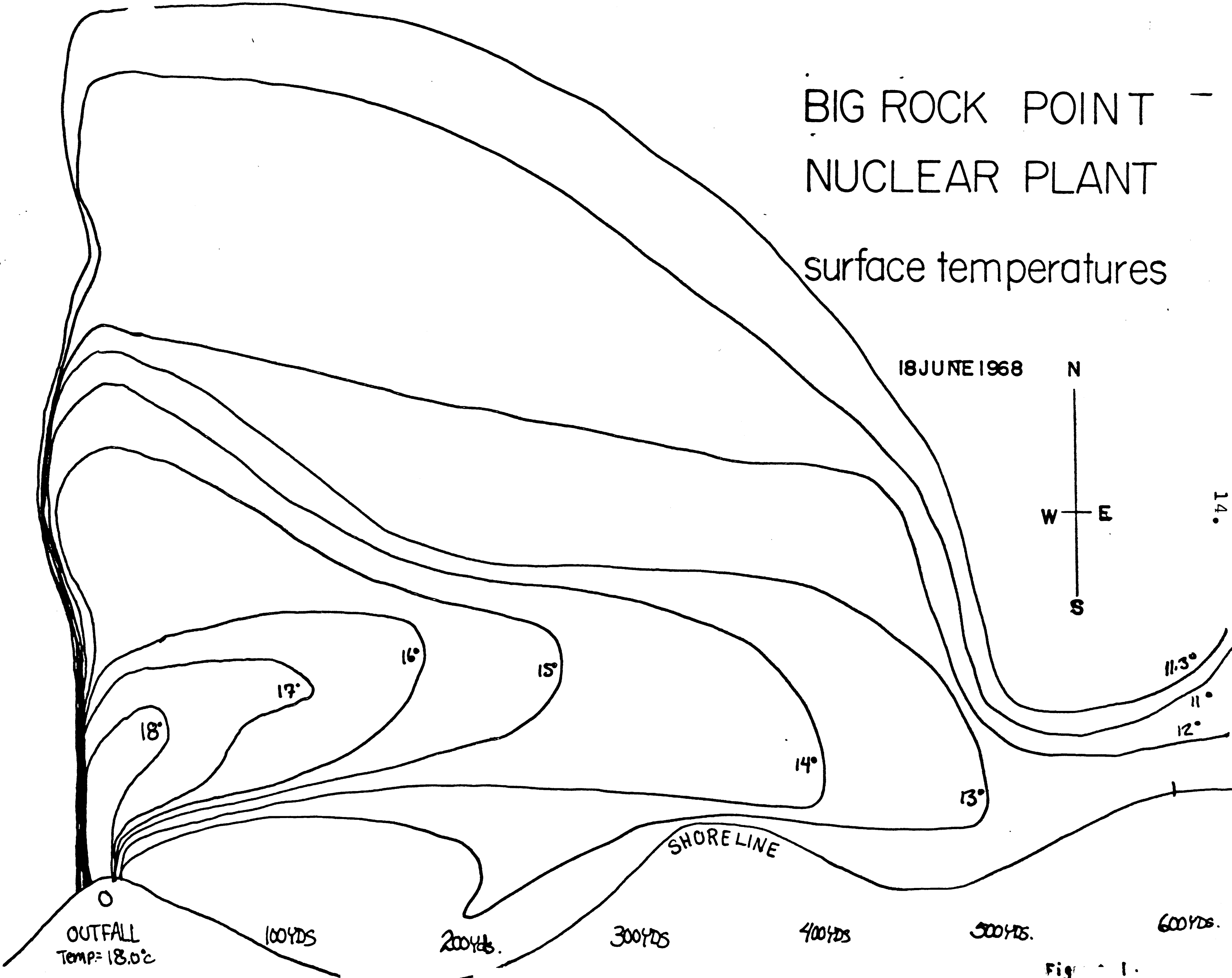
BIG ROCK POINT –
NUCLEAR PLANT
surface temperatures
18 JUNE 1968
N
W
E
S
11.3°
11°
12°
13°
14°
15°
16°
17°
18°
SHORE LINE
OUTFALL
Temp= 18.0°C
100YDS
200Yds.
300YDS
400YDS
500YDS.
600YDS.

Fig. 1.

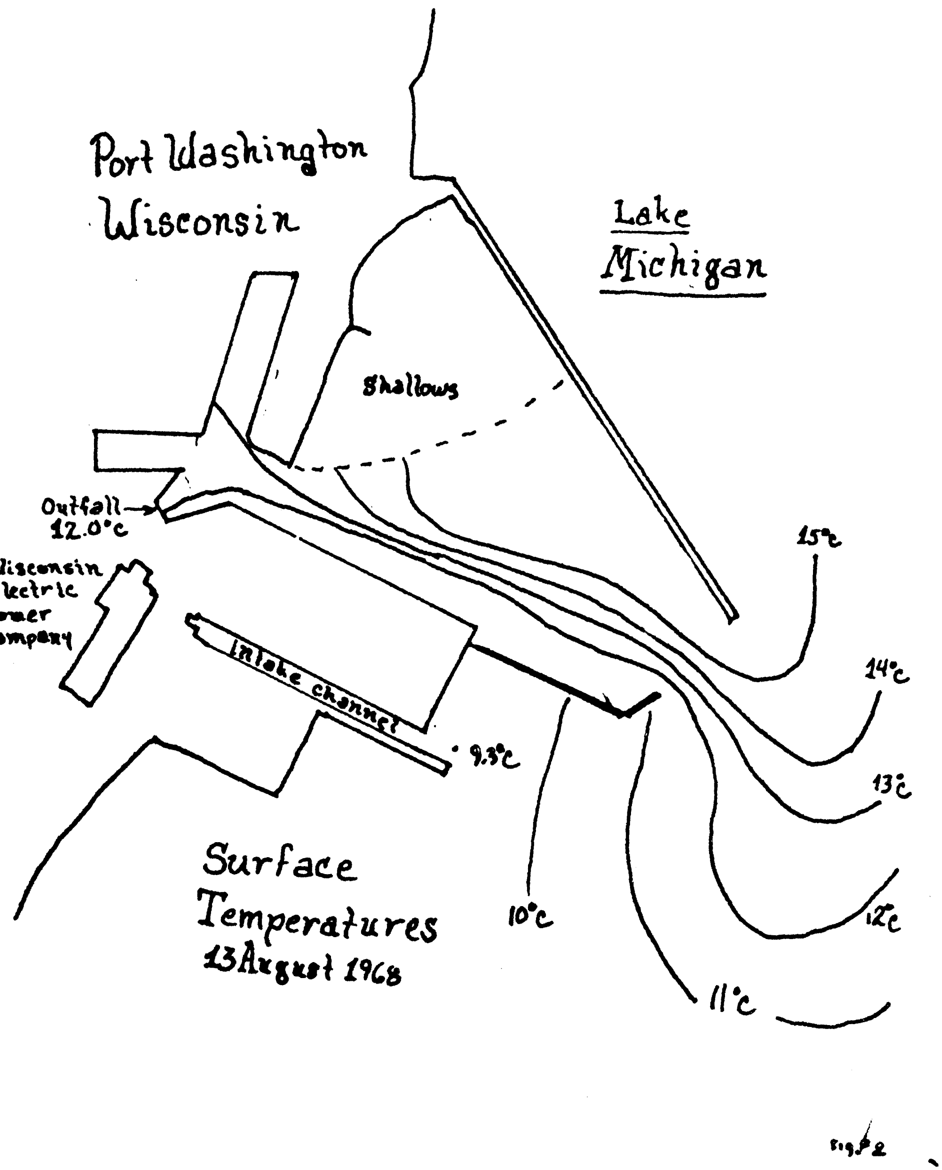

Figure 2. Port Washington Harbor Surface Temperatures.

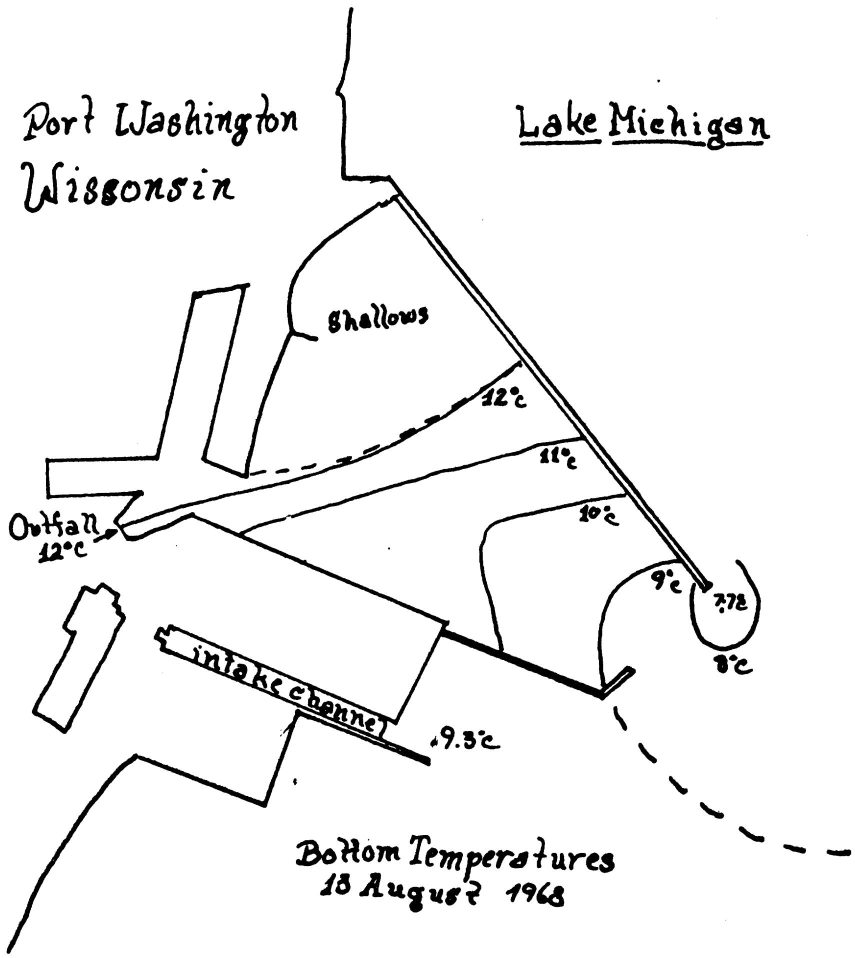

Fig 3.

Figure 3. Port Washington Harbor Bottom Temperatures.

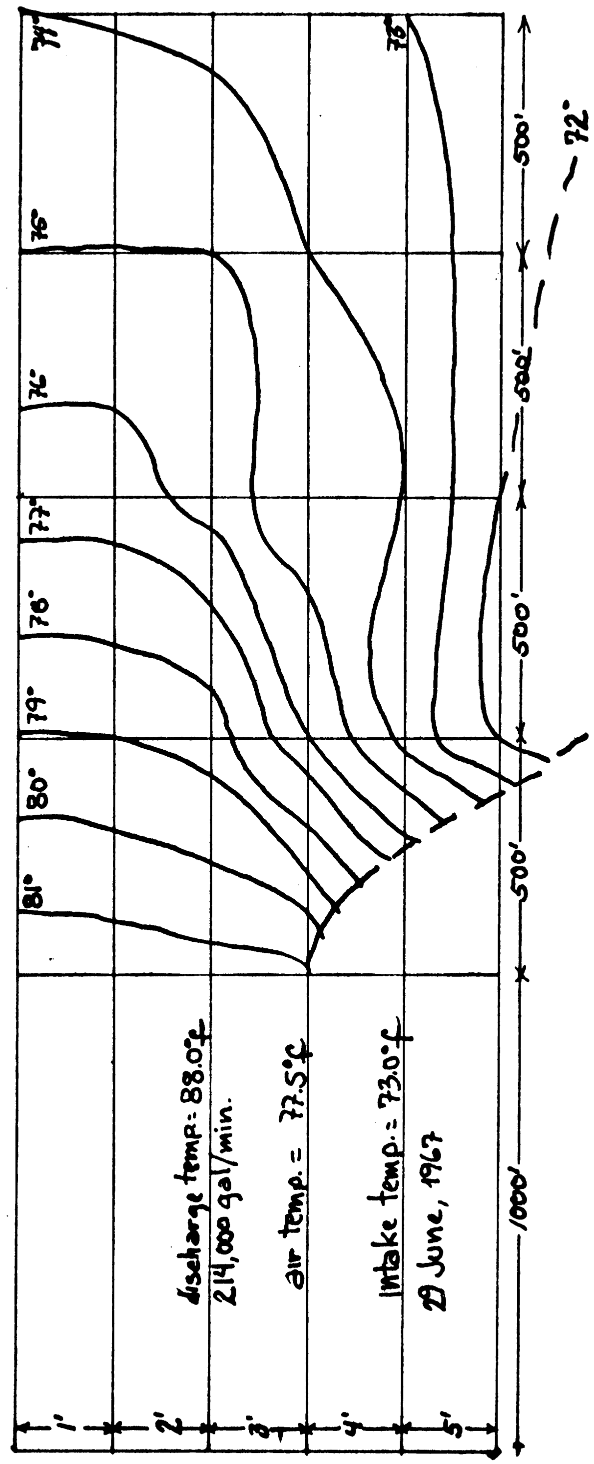

FIGURE 4. J.R. WHITING PLANT
CONSUMERS POWER COMPANY
VERTICAL TEMPERATURE SURVEY

Data kindly made available by Consumers Power Company from a survey made of their J.R. Whiting generating plant on Lake Erie are shown in Figure 4 in a vertical plot of temperatures to illustrate the floating of warmed, less dense water on the cooler lake water.

Benthos, Zooplankton, and Phytoplankton:

The biological data obtained are shown on Table 1. Where the benthos counts are zero, current scour on sandy bottom was encountered except at Station PW-13 where the bottom was of hard red clays and no benthos samples could be obtained. At Port Washington the zooplankton samples were taken with a #5 mesh net without a flow-meter and volumetric calculations could not be made. The phytoplankton samples at Port Washington and Port Sheldon were taken with a #20 mesh net; no flow-meter was available for the Port Washington samples and at Port Sheldon the meter was inoperative, so the figures are merely qualitative calculations based upon 1 ml. subsamples of the sample obtained.

The data followed the trends known to exist in Lake Michigan. The benthos, as Robertson and Alley (1966) pointed out, consist of Amphipods, Oligochaetes, Sphaeriids, and Tendepedids with other organisms such

Table 1. Biota Data, Lake Michigan Waste-heat study

Station #.	Temp. ^{o}C (Surf.)	Benthos/m^2	Zooplankton/l.		Phytoplankton/l.	
Charlevoix (26 October 1968)						
CX-4	14.5	0 (rock bottom)	15	D=2.92X10^4	(1m.) G=3.34X10^4	BG=2.45X10^4
				5.33X10^4	(18m.) 6.95X10^4	1.30X10^4
CX-5	14.8	1400	18	1.51X10^4	(1m.) 8.11X10^4	9.27X10^4
				5.38X10^4	(28m.) 1.06X10^5	1.30X10^4
Outfall channel	25.3	0 (sand)	40	6.18X10^4	(1m.) 8.58X10^4	8.61X10^4
Port Washington (13 August 1968)						
PW-1 (intake)	9.3	10200	-	1.22X10^8	2.78X10^6	1.39X10^6
PW-10 (harbor)	12.1	6400	43*	8.45X10^8	3.25X10^6	1.39X10^6
PW-13	11.0	-	335*	2.20X10^8	5.56X10^6	1.90X10^7
Port Sheldon (14 August 1968)						
PS-1 (intake)	17.0	700	1*	6.63X10^7	1.72X10^7	1.39X10^6
PS-2 (outfall)	26.7	0	0*	4.82X10^7	1.21X10^7	5.10X10^6

Table 1. Continued.

Muskegon (27 September 1968)						
MKG-CP1 (outfall)	26.7	1400	2	$5.82X10^5$	$2.33X10^5$	$2.36X10^4$
MKG-CP2 (intake)	20.4	3200	10	$1.11X10^6$	$4.47X10^5$	$2.92X10^4$
MKG-CP3	21.8	2100	15	$3.24X10^6$	$3.07X10^5$	$8,30X10^4$
MKG-CP4	21.1	2100	11	$2.50X10^6$	$2.86X10^5$	$5.10X10^4$
MKG-CP5	22.7	3000	7	$3.18X10^6$	$1.93X10^5$	$6.49X10^4$
MKG-CP6	19.7	2000	172	$1.19X10^6$	$4.16X10^5$	$5.66X10^4$

* Zooplankton samples taken without flow-meter or with inoperative meter. Samples qualitative only.

as leeches and isopods present. The zooplankton agreed with Wells' (1960) studies as to approximate numbers and species of copepods and cladocerans. Diaptomus sicilis (Czaika and Robertson, 1968), was not found in any of the inshore samples. The phytoplankton consisted of mostly diatoms with some of the typically warmer water green and blue-green algae present in amounts and species similar to those described by Stoermer (1967). No adverse trends, except for a slight decrease in numbers of organisms found in the power plant outfalls, were noted in the data collected.

Discussion

Benthos and Plankton samples were obtained from the plant intakes at Port Sheldon, Port Washington, and Muskegon. Plankton and benthos samples at Big Rock were taken under strong fall winds when safe boat operation near the submerged intake was impossible. Outfall samples were consequently taken from land.

At port Sheldon, Muskegon, and Big Rock, benthos and plankton samples of the outfall channels were taken from land. At Port Washington the outfall samples of benthos and plankton were taken at a station further from the outfall where the strong current had lessened and the boat could be more easily manuvered.

Benthos samples at the outfall stations of Port Sheldon, Muskegon, and Big Rock were in regions of heavy current scour from the cooling-water outfall.

Zooplankton numbers at Muskegon and Port Sheldon had decreased at the outfalls in comparison to the intakes. This would indicate that circulation through the condensers and/or the sudden heat change killed fair numbers of zooplankton. Charlevoix, however, exhibited a reverse trend, there being more zooplankton in the outfall than in the intake of the plant.

The value of these data are questionable, though, since the intake samples were taken one mile offshore while the submerged intake crib was only a few hundred feet offshore.

At Muskegon, the number of diatoms in the outfall was less than in the intake, indicating damage by heat or the condenser coils. No conclusions can be drawn on the phytoplankton, though, due to lack of quantitative samples.

No areas of overly abundant planktonic or benthic organisms were found.

Thus the detrimental effects of thermal pollution found in rivers and streams are not so detrimental in a lake situation. The warm, less dense, rapidly moving effluent, upon emergence into the lake, floats to the surface of the more dense cooler lake waters with very little mixing occurring due to the density differences. The biota of the water under the effluent plume are undisturbed because of this. Also, the cool water below the plume with specific heat equal to 1 doesn't change temperature as rapidly as the air above the plume with specific heat equal to about 0.25. Thus, as the plume dissipates its heat to the atmosphere, the water density becomes greater and mixing with the lake occurrs at or

near ambient lake temperature. Ayers (1965) has found that the mean temperature of Lake Michigan has been decreasing for the past 73 years, further indicating that the lake is not retaining power plant waste heat.

Because of the velocity of the effluent, the plankton drawn into the plant are heated, dumped into the effluent, and circulated with the plume into the lake, all within a few hours. This is hardly enough time for accelerated reproduction, especially after undergoing a thermal shock of 10-12°C. This is enough to account for the kill-off observed in the data. It should be noed that chemicals are often added to the cooling water before it enters the condensers to rid them of excess algae growth. This chemical additive might also account for the kill-off observed in the data. The vital capacity of organisms mentioned by Markowski (1959) holds for a warm pond situation but I am sure that if he had checked the biota in the plant effluent before it entered the cooling pond he too would have found decreased numbers of plankton.

The Washington Post of 6 February 1969 quotes (from a report not currently available) that the University of Maryland's Natural Resources Institute has estimated that plankton mortality, due to passage through a plant, can be as high as 94%.

In Conclusion, though this is a preliminary report, the ecosystems found along the shores of Lake Michigan near the power plant effluents are only slightly different from those found away from plant effluents, the main differences being slightly decreased numbers of benthos close to the effluent mouths due to current scour and decreased numbers of diatoms and zooplankton in the effluent plume found floating on the cooler lake water. It is not currently known how detrimental the decrease in biota is. If it were substantial and there were many more power plants, then the waste heat flowing from along-shore generating plants on Lake Michigan could be a problem for the lake's currently failing health.

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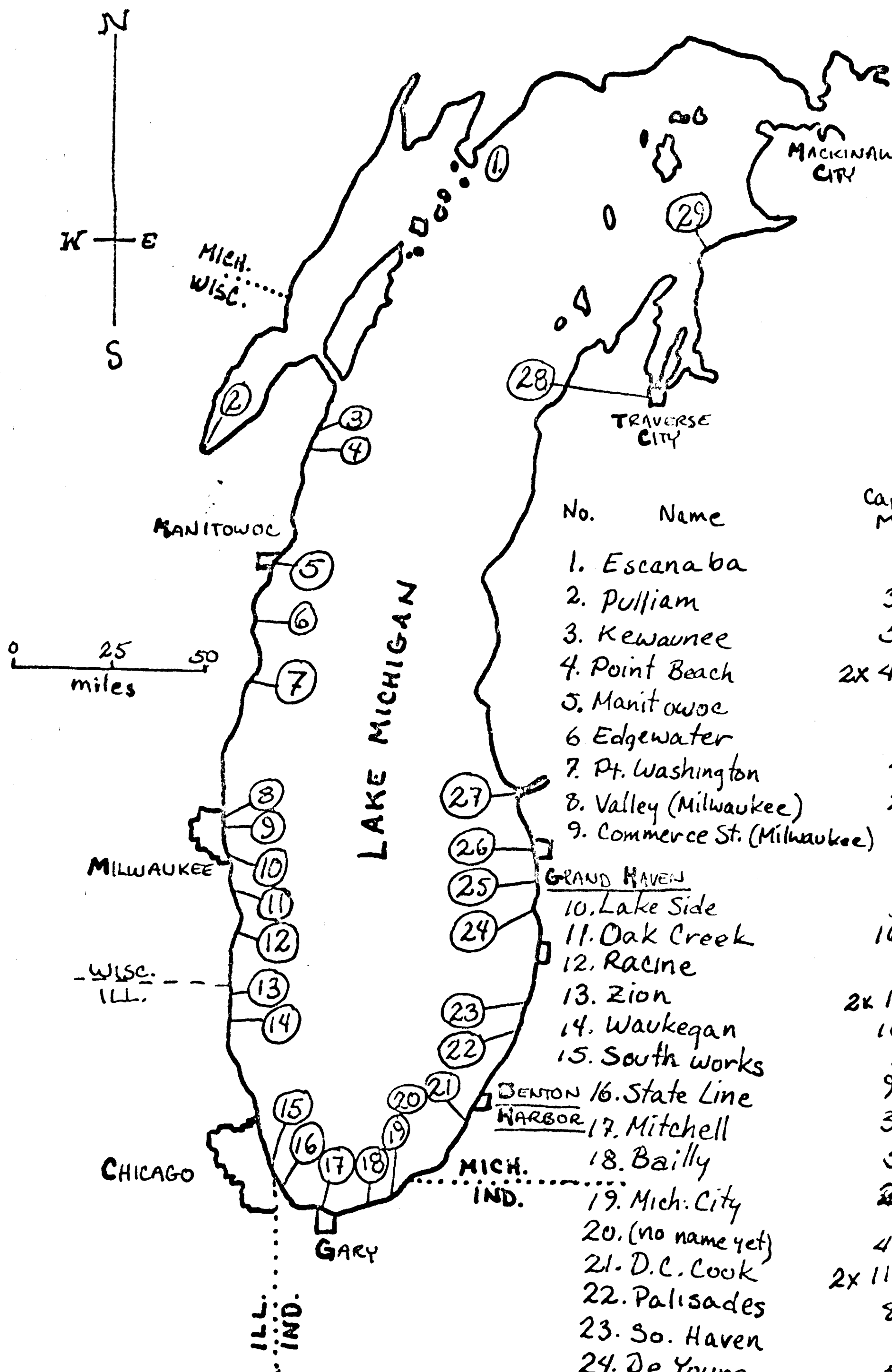
Appendix A.

Chart of the major power plants

of

Lake Michigan

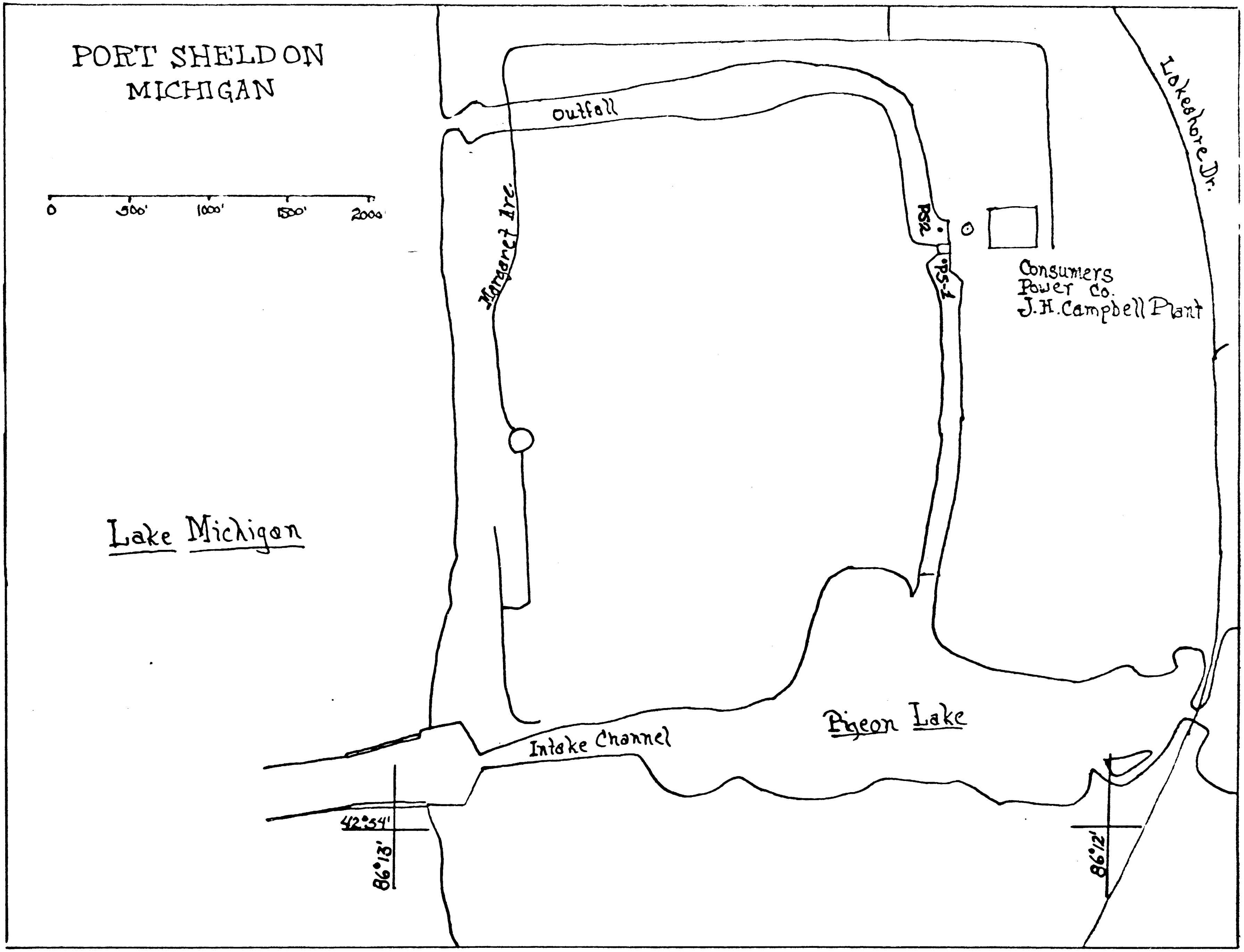


No.	Name	Capacity MW.	
1.	Escanaba	23	
2.	Pulliam	392	
3.	Kewaunee	527	NU 1972
4.	Point Beach	2x 497	NU 1971 & 72
5.	Manitowoc	52	
6	Edgewater	129 (+330 in 1969)	
7.	Pt. Washington	411	
8.	Valley (Milwaukee)	280 in 1969	
9.	Commerce St. (Milwaukee)	35	
10.	Lake Side	311	
11.	Oak Creek	1619	
12.	Racine	23	
13.	Zion	2x 1100	NU 1972 & 73
14.	Waukegan	1066	
15.	South works	105	
16.	State Line	923	
17.	Mitchell	390 (+115 1970)	
18.	Bailly	590	
19.	Mich. City	208	1973
20.	(no name yet)	400	1973
21.	D.C. Cook	2x 1100	NU 1972 & 73
22.	Palisades	811	NU 1970
23.	So. Haven	17.5	
24.	De Young	53.5	
25.	Campbell	650	
26.	Grand Haven	23	
27.	B.C. Cobb	510	
28.	Traverse City	15	
29.	Big Rock	75	NU

MAJOR POWER PLANTS

Appendix B.

Location of survey stations.


PORT SHELDON
MICHIGAN
0
500'
1000'
1500'
2000'
Lake Michigan
Outfall
Margaret Ave.
PS2
PS-1
Consumers
Power Co.
J.H. Campbell Plant
Lakeshore Dr.
Intake Channel
Pigeon Lake
42°54'
86°13'
86°12'

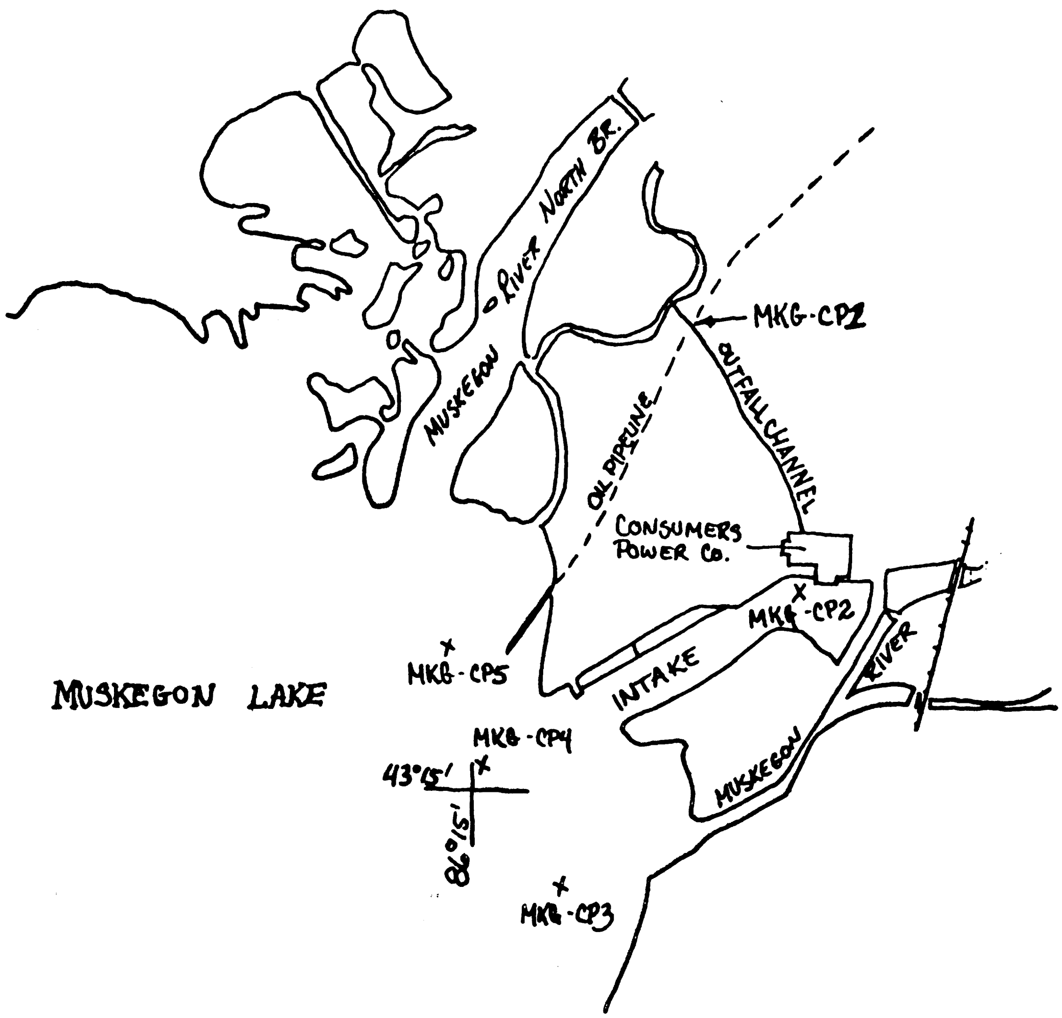
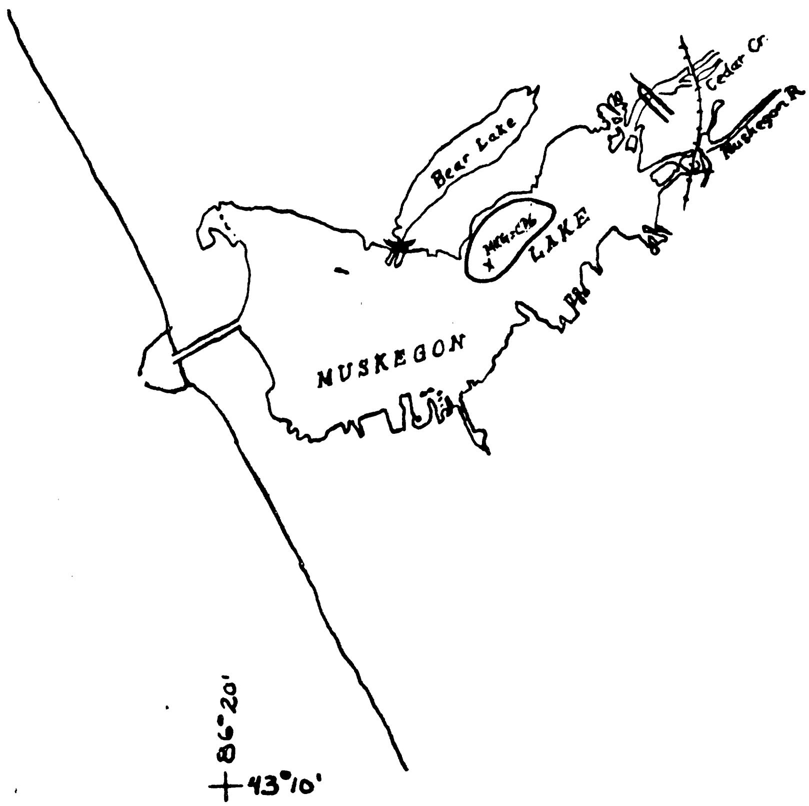


Figure 6. Muskegon Survey Stations.



9

Figure 8. Muskegon Lake Mid-lake Station.

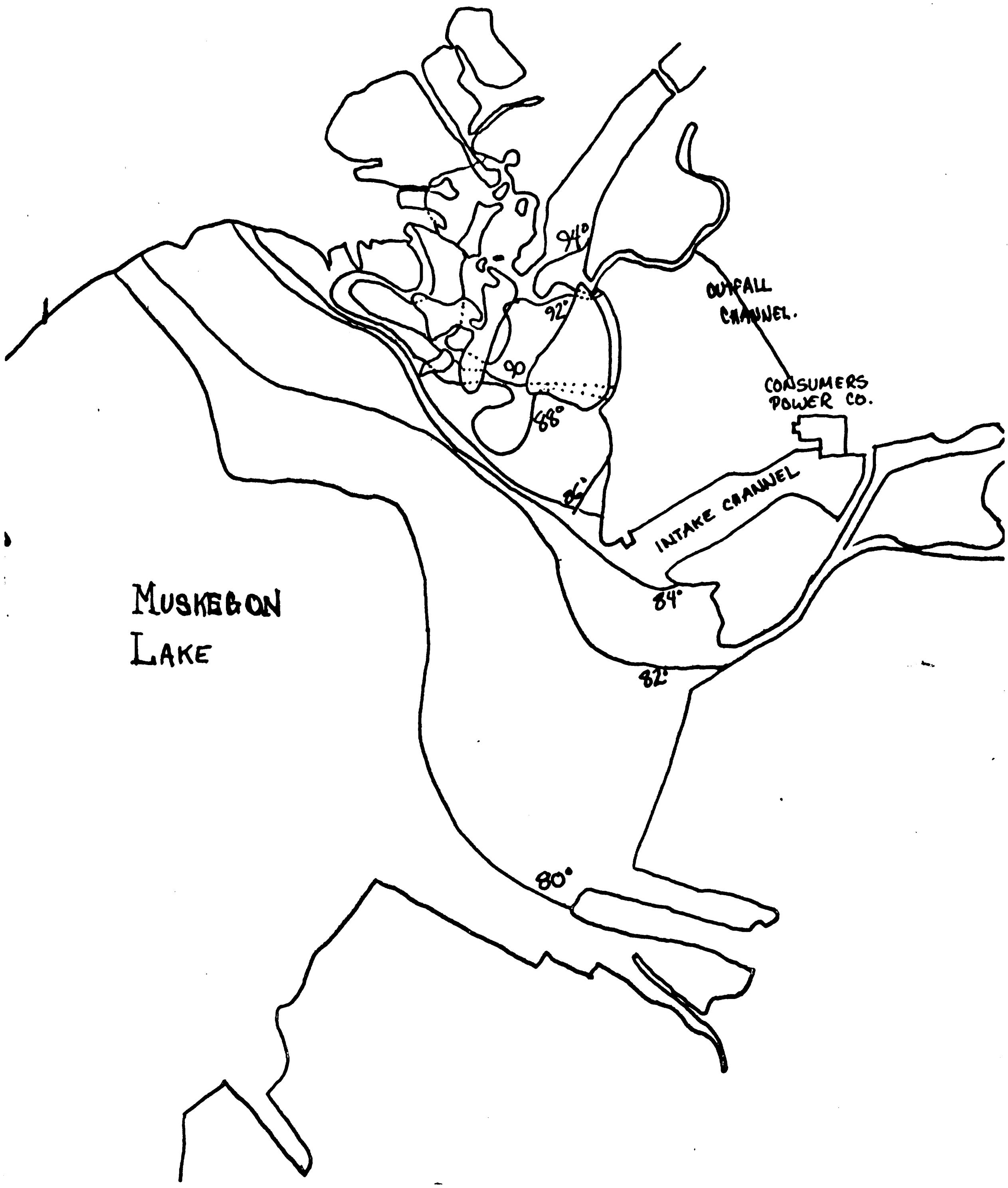


Figure 9. Muskegon Outfall Plume.

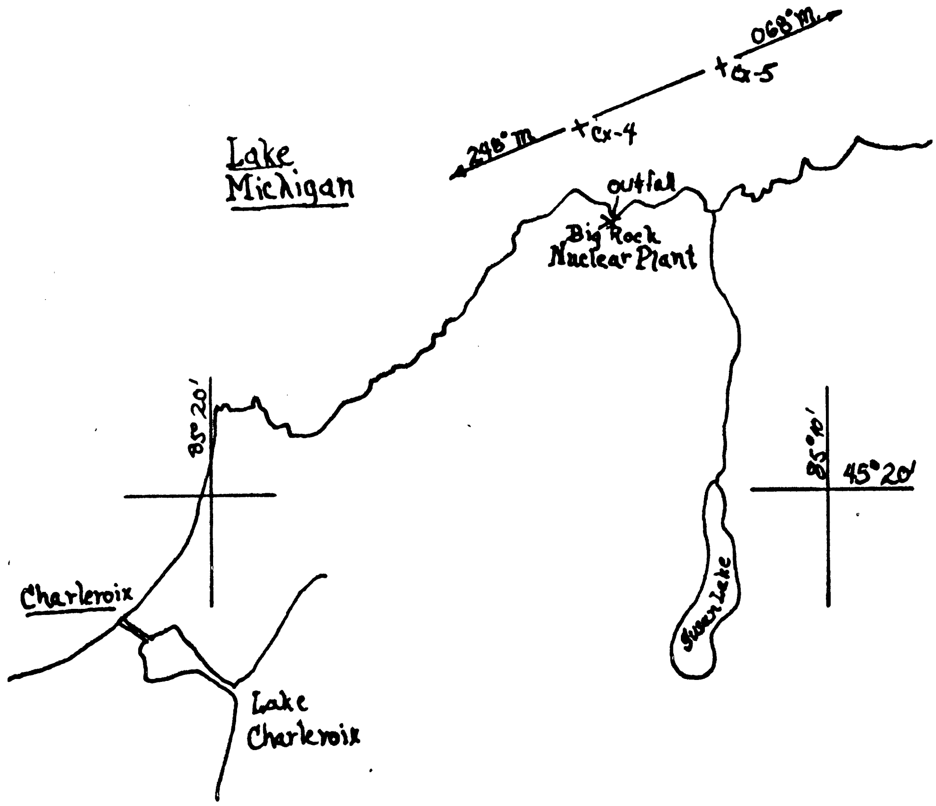


Figure 10. Big Rock Point Nuclear Plant Stations.

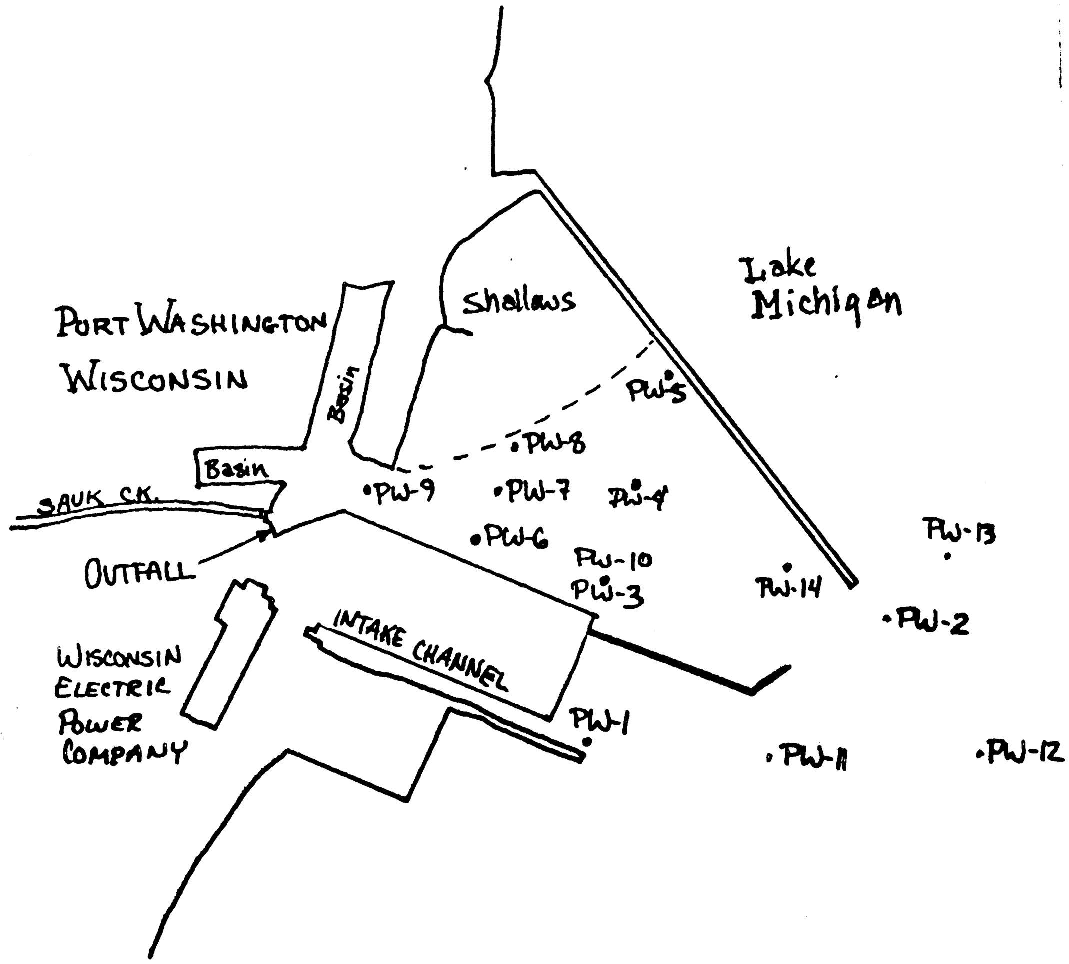


Figure 11. Port Washington Survey Stations.

Appendix C

Data from plume temperature studies.

B.C.Cobb Plant, Consumers Power Company, Muskegon Lake, Muskegon Michigan. Coal fired, 405,000 gpm cooling water flow, delta-T 10°F. Outflow temperature 94°F. Wind SW, 15 mph. Surface temperatures:

Station	2-A	94.3°F	Station	12-A	88.6
	2-B	93.1		12-B	80.7
	2-C	86.6		12-C	79.6
	2-D	-		12-D	79.4
Station	3-A	92.6	Station	13-A	87.5
	3-B	93.4		13-B	80.6
	3-C	93.0		13-C	79.8
	3-D	-		13-D	-
Station	4-A	86.0	Station	14-A	87.5
	4-B	90.6		14-B	81.1
	4-C	92.3		14-C	79.9
	4-D	94.3		14-D	-
Station	5-A	86.0	Station	15-A	87.2
	5-B	87.7		15-B	80.8
	5-C	91.3		15-C	80.2
	5-D	93		15-D	79
Station	6-A	91.0	Station	16-A	86.7
	6-B	84.5		16-B	81.7
	6-C	-		16-C	80.1
	6-D	-		16-D	80.4
Station	7-A	91.2	Station	17-A	86.2
	7-B	84.3		17-B	82.5
	7-C	83.8		17-C	81.2
	7-D	-		17-D	-
Station	8-A	90.5	Station	18-A	86.3
	8-B	83.0		18-B	83.7
	8-C	83.1		18-C	81.4
	8-D	-		18-D	-
Station	9-A	89.5	Station	19-A	86.6
	9-B	82.4		19-B	84.1
	9-C	82.7		19-C	81.3
	9-D	79.8		19-D	-
Station	10-A	89.0			
	10-B	81.9			
	10-C	80.9			
	10-D	79			
Station	11-A	88.4			
	11-B	81.1			
	11-C	79.9			
	11-D	79.3			

J.R. Whiting Plant, Consumers Power Company, Lake Erie. Coal fired, 214,000 gpm. cooling water flow, maximum delta-T 6°. Outflow temperature 88.0°F. Wind NE, 12 mph.

Station 1000'E, 500'N.

0 ft.	81.8°F.
1	81.6
2	81.4
3	81.4

Station 100'E, Centerline

0	75.5
1	75.5
2	76.0
3	75.0
4	73.0

Station 1000'E, 500'S.

0	70.0
1	71.5
2	71.5
3	71.5
4	71.5

Station 1500'E, 500'N.

0	79.0
1	79.0
2	78.5
3	76.0
4	73.5
5	72.0
6	72.0

Station 1500'E, Centerline

0	76.0
1	76.0
2	76.0
3	75.5
4	73.2
5	72.0

Station 1500'E, 500'S.

0	72.0
1	
2	
3	
4	
5	

Station 2000'E, 1000'N.

0	77.0
1	76.5
2	76.5

Station 2000'E, 1000'N, (cont.)

3	76.0
4	76.0
5	74.0
6	72.0

Station 2000'E, 500'N.

0	76.5
1	76.5
2	75.5
3	74.3
4	74.0
5	72.0
6	72.0

Station 2000'E, Centerline.

0	75.6
1	75.8
2	75.0
3	73.2
4	72.8
5	72.4
6	72.0

Station 2000'E, 500'S.

0	72.0
1	72.0
2	72.0
3	72.0
4	72.0
5	72.0

Station 2000'E, 1000'S.

0	72.0
1	
2	
3	
4	
5	

Station 2500'E, 500'N.

0	75.0
1	75.0
2	75.0
3	74.0
4	73.2
5	72.8
6	72.2

Station 2500'E, Centerline

0	72.0
1	
2	
3	
4	
5	
6	

Station 2500'E, 500'S.

0	72.2
1	72.2
2	72.0
3	
4	
5	
6	

Station 3000'E, 1000'N.

0	75.0
1	75.0
2	75.0
3	75.0
4	74.6
5	74.0
6	72.5

Station 3000'E, 500'N.

0	74.0
1	73.8
2	73.6
3	73.5
4	73.0
5	72.5
6	72.1

Station 3000'E, Centerline

0	72.2
1	72.2
2	72.0
3	
4	
5	
6	

Station 3000'E, 500'S.

0	72.0
1	
2	
3	
4	
5	
6	

Station 3000'E, 1000'S.

0	72.2
1	72.2
2	72.0
3	
4	
5	
6	

Port Washington Survey
13 August 1968

Wisconsin Electric Company, Port Washington Generating Plant. Coal fired, 500,000 gpm cooling water flow, maximum delta-T 6°, no water treatment ordinarily. Outflow temperature 12.0°C, 53.6°F. Light W. wind.

Station PW-1 (intake)

0 meters	0 feet	9.3°C	48.7°F
1	3.3	9.3	48.7
2	6.6	9.3	48.7
3	9.8	9.3	48.7
4	13.1	9.3	48.7
4.6	15.0	9.3	48.7

Benthos and plankton samples at this station.
Bottom: Slightly silty fine brown sand.

Station PW-2

0	0	15.0	59.0
1	3.3	12.2	54.0
2	6.6	10.3	50.5
3	9.8	9.1	48.4
4	13.1	8.4	47.1
5	16.4	8.0	46.4
6	19.7	7.8	46.0
7	23.0	7.7	45.9
8	26.2		
9	29.5		
9.1	30.0		

Station PW-3

0	0	12.1	53.8
1	3.3	12.1	53.8
2	6.6	12.1	53.8
3	9.8	12.1	53.8
4	13.1	11.5	52.7
5	16.4	11.0	51.8
6	19.7	10.5	50.9
6.7	22.1	10.3	50.4

Station PW-4

0 m	0 ft	15.3°C	59.5°F
1	3.3	13.5	56.3
2	6.6	11.8	53.2
3	9.8	10.0	50.0
4	13.1	10.0	50.0
5	16.4	10.0	50.0
6	19.7	9.9	49.8
7	20.1	9.9	49.8

Station PW-5

0	0	15.8	60.4
1	3.3	14.5	58.1
2	6.6	13.6	56.5
3	9.8	12.7	54.9
4	13.1	11.9	53.4
5	16.2	11.2	52.2

Station PW-6

0	0	11.9	53.4
1	3.3	11.6	52.9
2	6.6	11.4	52.5
3	9.8	11.2	52.2
4	13.1	11.0	51.8
5	16.4	10.8	51.4
5.5	18.2	10.6	51.1

Station PW-7

0	0	15.0	59.0
1	3.3	14.2	57.6
2	6.6	13.3	55.9
3	9.8	12.5	54.5
4	13.1	11.6	52.9
5	16.4	10.8	51.4
5.5	18.2	10.3	50.5

Station PW-8

0	0	14.9	58.8
1	3.3	14.0	57.2
2	6.6	13.0	55.4
2.4	7.9	12.6	54.7

Station PW-9

0 m	0 ft	12.5°C	54.5°F
1	3.3	12.7 ok	54.9 ok*
2	6.6	12.8 ok	55.0 ok*
3	9.8	13.0 ok	55.4 ok*
4	13.1	12.9 ok	55.2 ok*
5	16.4	12.8 ok	55.0 ok*
6	19.7	12.5	54.5
6.1	20.1	12.5	54.5

* Submerged outflow from sun-warmed creek and harbor basins.

Station PW-10 is PW-3 re-occupied for plankton and benthos samples. Bottom: 3" grey silt over hard red clay.

Station PW-11

0	0	12.8	54.3
1	3.3	12.3	54.1
2	6.6	12.1	53.8
3	9.8	12.0	53.6
4	13.1	11.5	52.7
5	16.4	11.0	51.8
6	19.7	10.4	50.7
7	23.0	9.8	49.6
8	26.2	9.3	48.7
9	29.5	8.8	47.8
10	32.8	8.8	47.8
10.1	33.0	8.8	47.8

Station PW-12

0	0	11.8	53.2
1	3.3	11.7	53.1
2	6.6	11.5	52.7
3	9.8	11.4	52.5
4	13.1	11.2	52.2
5	16.4	11.0	51.8
6	19.7	10.2	50.4
7	23.0	9.4	48.9
8	26.2	9.2	48.6
9	29.5	9.0	48.2
10	32.8	8.6	47.5
11	36.1	8.2	46.8
11.3	37.3	8.2	46.8

Station PW-13

0 m	0 ft	11.0°C	51.8°F
1	3.3	10.4	50.7
2	6.6	9.8	49.6
3	9.8	9.2	48.6
4	13.1	9.0	48.2
5	16.4	8.9	48.0
6	19.7	8.7	47.7
7	23.0	8.6	47.5
8	26.2	8.6	47.5
9	29.5	8.6	47.5
9.8	32.3	8.6	47.5

Plankton samples at this station, almost to end of visible plume. Bottom: Hard red clay, no sample obtained.

Station PW-14

0	0	15.5	59.9
1	3.3	14.4	57.9
2	6.6	13.3	55.9
3	9.8	12.2	54.0
4	13.1	11.4	52.5
5	16.4	10.6	51.1
6	19.7	9.8	49.6
7	23.0	8.9	48.0
8	26.2	8.9	48.0
9	29.5	8.9	48.0
9.8	32.3	8.9	48.0

Big Rock Survey

18 June 1968

Consumers Power Company, Big Rock Point Nuclear Generating Plant. Wind south 5-10 mph. Ambient lake temperature 10.7-11.3°C. Outfall temperature 18.0°C, top to bottom.

100	feet	offshore	north	of	outfall	mouth,	surface	18.0°C
160	"	"	"	"	"	"	"	18.0
240	"	"	"	"	"	"	"	18.0
300	"	"	"	"	"	"	"	17.9
400	"	"	"	"	"	"	"	15.1
600	"	"	"	"	"	"	"	15.9
800	"	"	"	"	"	"	"	14.5
850	"	"	"	"	"	"	"	13.9
950	"	"	"	"	"	"	"	11.3
1150	"	"	"	"	"	"	"	11.8
1350	"	"	"	"	"	"	"	11.3
1850	"	"	"	"	"	"	"	11.2

100 yards west of outfall:

100	feet	north	offshore	11.1
160	"	"	"	11.1
200	"	"	"	10.9
300	"	"	"	10.8
360	"	"	"	10.8
400	"	"	"	10.8
600	"	"	"	10.7
700	"	"	"	10.7
800	"	"	"	10.7
850	"	"	"	10.7

200 yards east of outfall

100	feet	north	offshore	13.0
160	"	"	"	12.9
200	"	"	"	12.9
300	"	"	"	13.6
400	"	"	"	15.2
500	"	"	"	16.0

600	feet	north	offshore	16.2
700	"	"	"	15.4
760	"	"	"	14.3
800	"	"	"	12.5
850	"	"	"	12.5
1050	"	"	"	12.0
1350	"	"	"	11.8
1750	"	"	"	11.3
2050	"	"	"	11.3

400 yards east of outfall (opposite tip of first point)

100	feet	north	offshore	
120	"	"	"	14.0
200	"	"	"	14.0
300	"	"	"	13.9
400	"	"	"	13.5
450	"	"	"	13.0
500	"	"	"	13.0
600	"	"	"	12.8
700	"	"	"	12.3
800	"	"	"	11.6
900	"	"	"	11.3
				11.3

500 yards east of outfall

100	feet	north	offshore	12.9
160	"	"	"	12.8
200	"	"	"	11.7
300	"	"	"	11.2
400	"	"	"	11.2
500	"	"	"	11.2

600 yards east of outfall

100	feet	north	offshore	11.8
160	"	"	"	11.8
200	"	"	"	11.2
300	"	"	"	11.1
340	"	"	"	11.1

700 yards east of outfall

160	feet	north	offshore	12.2
200	"	"	"	11.9
300	"	"	"	11.8
400	"	"	"	11.7
500	"	"	"	11.7
600	"	"	"	11.6
700	"	"	"	11.3
800	"	"	"	11.3
900	"	"	"	11.3